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REPORT

ON

SOME STUDIES RELATING TO THE CONTROL

OF

THE BLACK HILLS BEETLE

KAIBAB NATIONAL FOREST 1925

By

F.P.Keen,
Associate Entomologist
U.S. Department of Agriculture

Box 3010,
Stanford University, Calif.
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INTRODUCTION

In connection with the control work carried out on the Kaibab National Forest and Grand Canyon National Park during 1924 and 1925 by the Forest Service and Park Service which was directed against the Black Hills beetle in western yellow pine, considerable data of an investigative nature was secured by the writer on points relating to the effect of various methods of control, the susceptibility of trees to attack; the relation of losses to current annual yield and other problems relating to the habits and characteristics of these beetles. Some of these studies were outlined by Dr. Craighead and carried out in cooperation with Dr. Blackman, Mr. Edmonston and Mr. Hofer. Data on other points were secured incidentally in connection with the control work. Such of these studies as suggest certain conclusions have been summarized in this report. None of these conclusions can be considered as final but indicate certain leads which in some cases might profitably be followed further.

RELATION OF CONDITION OF TREES TO SUSCEPTIBILITY TO ATTACK.

The condition of the host trees often plays an important part in determining what trees are most apt to be killed by certain bark-beetles of the genus Dendroctonus. For instance D. brevicomis has been shown by Person to strongly favor the slow growing trees.

To determine if such factors as rate of growth, type and site conditions altitude or climatic influence were factors in determining this selection by the beetles, core measurements and other records were taken by the writer during 1925.

Rate of Growth.

Comparison of Pairs of Green and Killed Trees.

On the ridges east and west of Mile and a Half during July, pairs of trees of similiar diameter, one of which had been killed by the attack of 1924 and the other a green unattacked tree, were selected where there appeared to have been an evident selection on the part of the beetles. In no case were such green check trees taken more than fifty feet away from the killed tree. Many green check trees were selected within the circumference of a group of killed trees where the green tree was the only survivor. If there was any selection on the part of the beetles such trees should surely show it.

Increment cores were taken from the north side, at breast height on each tree, the cores measured and the growth compared. The width of each ring for the last ten years was measured, also the number of rings in the last half inch and the last inch were counted. The averages from these measurements by pairs of ten trees is given in Chart I.

The results of these measurements were as follows:
Number of cases in which killed tree was growing faster than the green check tree-

28 out of 50 showed faster growth for 1920
29 " " " " " " " 1921
33 " " " " " " " 1922
27 " " " " " " " 1923
33 " " " " " " " 1924 (year of death)
27 " " " " " " in last half inch
27 " " " " " " " " inch

Since the number of cases in which the faster growing tree was selected to be killed by the beetles were only slightly more than the number of cases in which the slow growing trees were picked, it might appear that the selection by the beetles had been purely indiscreminate. However, in plotting the comparative growth rate of any ten pair of trees, the killed trees are consistently about 10% faster growing than the green check trees (see Chart I). This then would indicate a slight degree of positive correlation between attack and fast growth, which probably means that there is some considerable degree of correlation between preference in attack and some other factor in which rate of growth is a secondary or dependent variable. For instance, the real correlation may be between selection and moisture while moisture is in its turn correlated with tree growth. This slight positive correlation with fast growth is at least interesting and may offer suggestions for further study.

Selection on Sample Acres.

Increment cores were taken from all the trees both green and killed in 1924 on two sample acre plots. These cores were measured and compared.

Sample Acre #1. Located on top of the ridge west of Three Lakes.
Pure yellow pine stand composed of

30	saplings	less than 6" in diameter	(normal)
6	poles	6" to 9" d.b.h.	"
6	"	10" to 19" "	killed in 1924
31	"	10" to 19"	normal.
25	trees	20" to 29" "	"
5	"	30" to 39" "	"
103	total number of trees.		

The group of six killed trees were taken as the center of the circular acre. This group represented an advanced group of new infestation which developed after the area had been treated in the spring of 1924. No trees of the 1923 attack could be found near by to explain where these attacking beetles had originated.

Cores were taken from the 73 trees above 6" d.b.h.

The slowest growing killed tree showed 34 rings in the last half inch. There were 10 other trees on the acre growing slower than this.

The fastest growing killed tree showed 7 rings to the last half inch. There was only one tree on the acre growing faster than this and two growing at the same rate.

Comparing the trees by diameter classes in which trees were killed:- (Killed trees are underscored).

Diameter	Growth Rate in Last Half Inch.
11	17, 22, <u>34</u>
14	11, 15, 17, <u>21</u>, 28
15	<u>7</u>, 13, 19
16	6, 7, 9, 9, 10, <u>11</u>, 14, <u>15</u>, 16, 21, 29

Comparing the growth during the last ten years of the six trees killed in 1924 with the sixteen green trees in the same diameter class, we find that on the average the killed trees were growing 5% slower than the green trees.

The rate of growth, therefore, for this sample acre does not appear to have been an important factor in determining the trees selected by the beetles.

Sample Acre #2. Located on a north slope in a slight draw on Section 22 T 38 N R 2 E near Murray Lake. A group of 13 trees killed in the fall of 1924 were selected as the center of a circular acre and cores taken from all of the trees over 6" d.b.h. on the acre. There was evidence of a previous killing by the Black Hills beetle on this acre, consisting of many old logs lying on the ground and still showing the markings of the beetles. Cores taken from the surviving trees showed that this epidemic had occurred in 1881, 45 years ago.

The stand was of pure yellow pine and consisted of

80	saplings under 6" d.b.h.	
49	poles 6" to 9" d.b.h.	normal
3	" 6" to 99"	killed
73	" 10" to 19"	normal
10	" 10" to 19"	killed
6	trees 20 to 29	normal
1	tree 30 to 39	normal
222	Total number of trees.	

The slowest growing tree attacked by beetles showed 52 rings to the last half inch. There were three other green trees growing slower than this and four others growing at the same rate.

The fastest growing killed tree showed 10 rings to the last half inch. There were four other trees growing faster than this and two others growing at the same rate.

Comparing the growth rate of killed trees and normal trees of the same diameter we have the following: (Killed trees are underscored.)

D.B.H.	Growth Rate In Last Half Inch.
8"	24, 28, 30, 41, 43, 52.
9"	10, 16, 16, 18, 19, 21, 29, 30, 31, 33, 34, 35, 38, 38, 44, 46, 52, 52.
10"	8, 11, 12, 13, 13, 14, 20, 25, 27, 34, 35, 42, 45, 48, 52.
11"	14, 17, 19, 19, 22, 22, 24, 26, 37.
13"	12, 12, 14, 16, 17, 17, 18, 20, 21, 25.
16"	12, 14, 18, 19, 20, 30.
18"	10, 11, 12, 12, 15, 17, 18.

It is evident from the above comparison that the killed trees were not selected on account of slowness of growth. In three diameter classes the fastest growing tree was killed.

Relation of Type and Site Conditions.

During the recent epidemic on the Kaibab, it has been noted that the heaviest losses occurred in the pure yellow pine stands along the border of the mixed type and on the tops of ridges. The beetles also killed many trees through the lower edges of the mixed stand but no heavy killings were noted through the spruce type, probably because of a lack of any number of host trees. Through the lower limits of the yellow pine stand, especially where it is mixed with juniper, very few trees were killed by the Black Hills beetle, this species being replaced in this type by D. barberi, which appears to prefer the drier sites and in this respect resembles its near relative D. brevicomis in Oregon and California.

The beetles also show a preference for the heavier stands, where there is some competition between the trees. Wherever a large area of forest is destroyed, almost invariably a fringe of green timber will be left around the edge of the parks and openings. Cores taken from a number of these trees showed them to be particularly fast growing, since they had few neighbors and very little competition.

Although some trees are killed by the Black Hills beetle from the lower limit of the yellow pine to the highest elevations on the mountain, it has been noted by the writer that the heaviest epidemic losses have occurred between the 8,000 and 8,500 feet contours. Just why the beetles should prefer this belt of timber is difficult to say but it is probably due to temperature and moisture conditions which are most favorable for beetle development. Shreve[1] has shown that there are very striking gradients of vertical change for precipitation, soil moisture, evaporation and certain elements of the temperature which occur from the lower to the higher elevations in the yellow pine forests of Arizona. These moisture and temperature conditions which are so favorable to the best development of yellow pine at certain elevations may also be the moisture and temperature conditions which are optimum for beetle development. Thus the apparent preference by the beetles for fast growing trees may simply be a correlation incidental to the selection by the beetles of a moisture and temperature zone which corresponds with the zone of best tree growth.

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A similiar observation was made by Graves[2] in his report of the Black Hills epidemic in 1897 in which he says "The injury is confined to the limestone formation and to high elevations".

The records from the survey of 1925, also failed to show any evidence of the prominent beetle epidemics of the last 75 years below the 8,000 foot contour, although these epidemics occurred throughout the forest above this elevation. Such loss as did occur below the 8,000 foot contour was so very old that the cause could not be definitely associated with the Black Hills beetle.

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1. Shreve, F. - The Density of Stand and Rate of Growth of Arizona Yellow Pine As Influenced by Climatic Conditions. Journal of Forestry 15: 695-707 Oct. 1917.

2. Nineteenth Annual Report U.S. Geological Survey, 1897-98 Par. V page 87.

PAST EPIDEMICS ON THE KAIBAB.

The Black Hills beetle has left a written history of its activities during the past centuries in the living trees. The evidence of beetle work left in the growing trees together with the evidence left on the ground in the form of rotting logs, can be fairly accurately read for the last 75 years. The logs with the markings of the beetles egg galleries show where a group of trees have been killed, and an increment core taken from the surviving trees will generally show the year in which the tree was released from suppression through the death of its neighbors. Often a ring just previous to this release will show a pitch pocket where the cambium had been injured by a beetle attack but had healed over the the tree had survived. This previous history was first brought to our attention by Dr. Craighead when he visited the Kaibab in 1924. He secured a number of samples showing the work of the beetles at earlier periods, one sample showing an attack which had been made 247 years ago. He suggested, therefore, that it might be possible to back date a number of the more important epidemics and learn how extensive they were and when they occurred.

The survey of 1925 offered an opportunity to do some of this work and obtain a few records from different portions of the plateau. Throughout the survey wherever old beetle killings were encountered, increment cores were taken from the surviving trees. By counting back to the year of release the date of the old killing was determined. The following notes were secured. Rings which showed the markings of the beetles are underscored.

T 39N, R 1 E Sec. 25 (west of Jacob Lake) No beetle killings of any importance within the past 50 years. Some evidence of very old killings or fires.

T 39N, R 2 E Sec. 22 (east of Jacob Lake) Only a few small areas not over 4 acres in extent killed within the past 50 years. Years of loss 1866, 1882, and 1886.

T 38N, R 1 E Sec. 23 (near Mud Lake) No epidemic killings within the last 50 years of any size. Old openings, possibly from beetle epidemics now with heavy reproduction up to five feet in height.

T 38N, R 2 E

Sec. 17 (west of Three Lakes) Small group of trees on ridge killed in 1826.

Sec. 15 (north of Murray Lake) Several one to two acre patches of fairly recent beetle killing.

Dates:- 1855, 1881, 1886, 1888, 1890, and 1910.

Sec. 34. (east of Mile and Half) Numerous small patches of old killings from ¼ to 2 acres in area.

Dates:- 1860, 1878 to 1882, 1896, 1902.

T 36N, R 1 E

Sec. 5 (west of Potato Patch) No old killings evident.

Sec. 24 (west of Dry Park) Several very large areas of pine completely killed about 35 years ago. Killings aggregate about 50 acres.

Dates:- 1879 to 1884.

T 36 N, R 2 E.

Sec. 15 (north of Lookout Lake) Several small patches of old killing. None within the last 50 years.

Sec. 31 (southwest of Dry Park) Several small killed areas, less than an acre in extent.
Dates:- 1879 to 1881.

T 36 N, R 3 E.

Sec. 16 (east of Pleasant Valley) Large areas of pine killed within the last 50 years (about 20 years and 45 years ago) Nearly 75% of pine on the section killed in these old epidemics. (One of the important areas noted in the Forest Service reconnaissance of 1910)
Dates:- 1879 to 1880, 1888, 1899, 1904-1905 - 1906.

T 35 N, R 1 E.

Sec. 24 (north of Quaking Asp.) Several old killings of small extent.
Dates:- 1876, 1880.

T 34 N, R 2 E.

Sec. 15 (north of Kanabownitts) Many small patches of yellow pine killed. Over 50% of pine killed by beetles throughout the mixed stand.
Dates:- 1867, 1879-1880.

T 33 N, R 4 E

Sec. 34 (south edge of upper Greenland) One large area nearly three hundred acres in extent and many small areas killed by beetles about 1906. Noted as bug killed and mapped by Forest Service reconnaissance crew in 1910.

Thus there is ample evidence throughout the Kaibab forest of many previous epidemics of the Black Hills beetle, and an almost continous killing of some trees. The most severe epidemics occurred during the periods 1860 - 1866, 1879 - 1884, 1902 - 1906, and 1920 to 1925. But it is impossible to say just how much timber was killed at any one time, or what the beetles were doing between these epidemic periods. It is especially interesting to note that these epidemics occurred at intervals of about 20 years and were of approximately 5 years duration.

RELATION OF CLIMATIC INFLUENCES UPON BEETLE EPIDEMICS.

The collective physiological process of trees is represented by their growth rate. This may either be measured by height growth or by increase in diameter. Since the annual growth of yellow pine is well defined by rings of light and dense wood, this ring growth becomes the most accessible record of the various factors which have been of importance in the trees development. Of these factors moisture is probably of the greatest importance.

Douglass[1] after many years of exhaustive study has shown the very close relationship which exists between tree growth and climate. Some of his more important conclusions are that:-

1 "Variations in annual rings of individual trees over considerable areas exhibit such uniformity that these same rings can be identified in nearly every tree and dates established with practical certainty. In dry climates the ring thickness is proportional to the rainfall with an accuracy of 70%.

2 "A most suggestive correlation exists in the dates of maxima and minima found in tree growth, rainfall, temperature and solar phenomena".

The pattern of ring growth for the Kaibab area was determined by measuring the width of rings for the last 75 years of ten trees from widely separated points on the mountain. Douglass has found that 5 trees is enough to secure this pattern with a sufficient degree of accuracy . The ring pattern from the Kaibab cores checked very closely with that found by Douglass in trees from Flagstaff and Prescott, Arizona, and also showed many points in common with the ring pattern of yellow pine at Klamath Falls, Oregon. This phenomena of similiar fluctuations in tree growth by years for trees in Arizona and California has been observed by Douglass and as pointed out by him indicates that Arizona and California although with apparently quite different climates are still in the same meteorological district.

Accepting Douglass' conclusions, we have therefore, in the ring pattern of the trees a history of the important climatic changes which have occurred during their lifetime, which for the Kaibab trees means a history of the last 300 or more years. This history shows a rythmic cycle of drought periods and wet years, occurring at intervals of about 11 or 22 years. These are the same cycles which have been observed in the occurrence of sunspots, 11 years representing a full sunspot cycle and 22 years a double sunspot cycle.

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1. Douglass, A.E. Climatic Cycles and Tree Growth.

Comparing the fluctuations in tree growth and the periods of the epidemics which have been previously determined, we find a very close correlation between the epidemics and the periods of slow growth or drought periods. (see Chart 2) This is particulary noticeable in the epidemics of 1879 to 1884 and 1896 to 1906.

Plummer[2] in his report of the Black Mesa Forest Reserve in Arizona (now the Apache National Forest) written in 1903 speaks of the severe drought which had prevailed during the previous eight years and its effect upon the pine timber of that region.

"The scarcity of precipitation which for the last eight years has afflicted this region is shown by the conditions of the yellow pine, aligator juniper, and Arizona Cypress, which trees, as a rule, stand an extreme drought. In the vicinity of Heber, the scattering growth of yellow pine is rapidly being killed --- and the whole of them are dead or so far diseased as to be beyond resuscitation. At Blue postoffice, --- the effects of the excessive heat and drought are still more marked, and large areas of sparsely timbered country will lose hundreds of thousands of feet of timber unless it is immediately logged". Undoubtedly insects were the immediate cause of the death of these trees, with drought the primary contributing influence.

One of the most extensive killings on the Kaibab which occurred during this drought period was located on the southwestern portion of Greenland plateau in section 34. Here the timber over 300 acres or more was almost completely wiped out by the beetles. The logs now lay strewn about forming a jackstraw tangle of decaying sticks through which some few young trees are growing.

The recent epidemic which probably started in 1919 and reached a peak in 1922 also coincides with a period of slow growth and a period of drought, as shown in Chart 2 .

Since it has been shown that this beetle does not prefer the slow growing trees, it is most probable that the drought periods have their influence directly upon the beetles themselves in producing temperature and moisture conditions most favorable for their development, rather than in making the trees more susceptable to attack through the slowing down of their growth.

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2. Plummer, F. G. Carnegie Institute Pub. 289.
Forest Conditions in the Black Mesa Forest Reserve, Arizona.
U.S. Geological Survey Professional Paper #23, 1904.

CORRELATION OF BARK COUNTS AND NEW INFESTATION.

At the suggestion of Dr. Craighead, bark counts were made over various portions of the Kaibab Forest during July 1925 by Dr. Blackman, Mr. Edmonston, Mr. Hofer, Mr. Jim Henry and the writer. The bark was carefully removed from one or two square feet on each 10 ft. log of infested trees and the total number of live Black Hills beetles counted.

These bark counts have been summarized by Dr. Blackman and used in various ways to show the existing relationships between various factors, such as growth, size of tree, crown density, site, slope, exposure, and the status of the infestation.

With the data secured in the fall survey of 1925, it is now possible to show the relationship between the beetle population which emerged in various regions and the subsequent infestation in the same region.

In Table 1 we have a comparison of the bark counts with the estimated number of trees attacked per section in 1925.

TABLE 1.

Comparison of Bark Counts with Intensity of Infestation.

Location	Average No. Beetles emerging per sq. ft. in 1924 attacked trees.	Estimated No. trees attacked in 1925 per sec.
Mile & Half, East Slope	12.91	600
Murray Lake - Top of Ridge	9.49	100
Near Highway east of camp. N.E. slope	7.83	20
Mile and Half Top of Ridge	7.11	140
Corrall Lake	5.49	70
Bee Spring	5.21	50
Dry Park Sec. 24.	4.7	30
Old Control of 1924-N.E. of Mile and Half	3.8	40
Dry Park, Sec. 31	3.16	5
Fracas Lake- Top of Ridge	2.04	20

This table indicates a very good correlation between emerging beetle population and the quantity of the subsequent infestation. In the highly epidemic areas more beetles emerged from the trees than in the old epidemic areas or under endemic conditions.

We therefore assumed that the bark counts would indicate the more aggressive areas of infestation and where the heaviest emergence occurred there would be found the heaviest percentage of new infestation. But this apparently is not the case.

TABLE 2

COMPARISON OF BARK COUNTS AND PERCENTAGE OF NEW INFESTATION.

Location.	Av. No. Beetles emerging per sq. ft. in 1924 attack trees.	Number of newly infested trees (1925 attacks) per 100 of old infestation.
T 35 N, R 1 E, Sec. 4 (S. of Bee Sprg.)	(5.21)	48.5
T 39 N, R 1 E, Sec. 25 (W. of Jacob)		32.4
T 38 N, R 1 E, Sec 23 (Mud Lake)	(2.04)	24.6
T 38 N, R 2 E, Sec 15 (Control of '25)	(9.49)	21.7
T 36 N, R 1 E, Sec 5 (Potato Patch)		19.3
T 37 N, R 1 E, Sec 11 (Moquitch Ridge)		17.8
T 38 N, R 2 E, Sec 10 (Control of '25)		17.1
T 36 N, R 2 E, Sec 15 (Lookout Lake)		17.1
T 39 N, R 2 E, Sec 22 (East of Jacob)		15.8
T 38 N, R 2 E, Sec 34 (Old control '24)	3.87	14.9
T 37 N, R 2 E, Sec 8 (W. Mile & Half)	7.11	11.8
T 36 N, R 1 E, Sec 24 (Dry Park)	4.7	7.3
T 35 N, R 1 E, Sec 24 (Quaking Asp)		5.9
T 37 N, R 1 E, Sec 25 (Oquer Canyon)		3.5
T 36 N, R 2 E, Sec 31 (Dry Park)	3.16	3.3
T 37 N, R 2 E, Sec 35 (Franks Lake)		0
T 34 N, R 2 E, Sec 15 (Kanabownits)		0

This arrangement shows that the highest percentage of new infestation occurred in sections several miles from the older epidemic areas, which were not as yet epidemic, but where the infestation was increasing. Thus the section south of Bee Spring showed the most aggressive new infestation, with other sections west of Jacob and Mud Lake next in order. Section 8 in T 37 N, R 2 E just west of the Edmonston camp at Mile and a Half, although having the greatest amount of new infestation (about 600 trees per section) only showed 11.8 newly infested trees per 100 trees of the previous generation.

In tabulating the available bark counts for these sections, we find that there is no indication of any correlation between these two variables. This is a rather startling discovery, and we are at once confronted with the question of its significance.

One explanation may be that in the heavily infested centers, the trees are so completely attacked that a heavy emergence per square foot is assured. But after emergence, the new beetles find considerable difficulty in finding enough suitable host material (as most of the susceptible trees have been previously killed) and thus they are unable to maintain a high ratio of new attacks. On the other hand in the endemic areas, the trees have been feebly attacked and only the inferior and weakened trees succumb. From these trees poor broods develop, but the beetles which do emerge have no difficulty in finding plenty of suitable host material and so are able to make good a high percentage of their attacks. They may also receive assistance from other beetles immigrating into the section from epidemic centers where conditions for new attacks are unfavorable.

This and other evidence points to the general conclusion that beetle population is only one of the factors in determining the amount of new infestation which may develop and it is often of less importance than other factors of which we know very little at present. Therefore, the success of control work, in which the beetle population is reduced, may be relatively successful or unsuccessful depending, not upon the thoroughness with which it is done but upon other factors which favor or oppose successful beetle attacks and development.

The data presented above are frankly inadequate as a basis for conclusions. Not enough bark counts were made in the various localities to give a sufficient number of comparisons. The data do however, open up a question which should receive further study, as it may throw some light on the causes behind the increases of infestation in new centers and the success of control work.

RELATION OF LOSSES TO FOREST INCREMENT.

In order to properly evaluate the insect damage to a forest we should know how many years it will take for the forest to recuperate after an insect epidemic.

In the long run, a forest, if it maintains itself, must reach a balance between its increment and its losses. If the increment should be in excess of the losses, the stand would continue to increase and in time would reach a point where the land would no longer be able to support the growth. If on the other hand the losses were in excess of the increment, the forest would eventually be wiped out. Neither of these two things have happened on the Kaibab. Many years ago it reached a balance between its losses and its increment and became a mature forest. How many years then does it take for these factors to become equalized and what agencies are responsible for the losses?

The cores taken from the two sample acres offered an opportunity to gain an idea of the yearly increment of the yellow pine on the Kaibab. Of course, two acres are not adequate for this purpose, but still they give an indication of the conditions and taken together with yields of similiar forests in the region give a basis for an estimate.

Sample Acre #1 showed an annual increment of 146.7 board feet per acre per year for the last 39 years. This represents an annual increment of .50% of the stand. (see computations in appendix)

Sample acre #2 showed an annual increment of 130.0 board feet per acre per year for the last 37 years, which represented an annual increase of 1.02% of the stand. Assuming an annual increment of 1% for the entire stand of 1,101,375 M.B.M. of yellow pine, the total annual increment would be 11,014,000 board feet.

If we deduct from this total increment the amount of endemic losses, 2,430,000 board feet which the recent survey showed may occur from year to year, the net total increment would be 8,584,000 board feet.

The recent epidemic killed 146,000,000 board feet which was therefore equal to the net increment for the last 17 years. With epidemics occurring at intervals of about 20 years as they have in the past, it seems evident that 85% of total forest increment has periodically been wiped out through insect losses and the balance in the forest maintained.

Therefore, if the losses are replaced by increment in twenty years there is no need to worry over the insect losses provided the forest is not going to be used within that period. If, however, there is a chance that the timber will be cut within 20 years, every effort should be made to protect the present stand in order to get a larger and better quality cut.

METHODS OF DIRECT CONTROL

Peeling Method.

The first method of control of the Black Hills beetle advocated by Dr. Hopkins[1] was the felling and barking of the infested trees. This method was used successfully in several control projects in Colorado and was used throughout the control work on the Kaibab during 1922, 1923, and 1924.

When trees are very limby, dry and the bark sticks tightly, peeling is not only a difficult task but is also expensive. When the bark is moist and has been completely loosened by the feeding beetles, peeling is easily accomplished.

Without excessive precautions, it is impossible to get 100% kill of beetles by use of the peeling method since some infested bark is almost sure to be left in places where it is difficult to reach. To determine what percentage of kill could be expected from this method a series of 50 trees peeled by the Forest Service control crews in May 1925 were examined by the writer in July 1925. Of these, 39 trees showed 100% kill of the Black Hills beetle. The other 11 trees showed an average of 86% of the bark peeled and the brood destroyed. This means that this method is roughly 97% effective in destroying the broods.

The cost of treatment varies directly with the cost of labor, the diameter of the trees, the infested length; and is materially affected by such other factors as influence the efficiency of the crew. From curves plotted for work carried out on the Kaibab during 1924 and 1925, giving time of treatment for trees of different diameters the following empirical cost formulae was deducted:

For trees felled, trimmed and the infested length peeled.

$$C = c\,(.066D^2 + .105DL + 10)$$

in which

C = Total cost per tree.
c = cost per man minute of treaters time.
D = Average diameter of trees treated.
L = Average Infested Length.

The above formulae with some slight change in the constants will apply to the cost of peeling any trees where similiar methods are used.

For the average tree on the Kaibab 20" d.b.h. and 40 feet infested with a cost per man minute of .1½ cents, the average cost would be $1.65

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1. Hopkins, A.D. Insect Enemies of the Pine in the Black Hills Forest Reserve, Bull. #32 U.S. Dept. Agr. Div. of Ent. 1902.

The Burning Method.

The method of felling the trees, peeling the bark from the upper half of the fallen log and burning it along the log is used extensively through California and Oregon in the control of the western pine beetle. The application of this method to the treatment of the yellow pine infested with the Black Hills beetle was first suggested by Mr. Miller when he visited the Kaibab in 1923.

The method was first tried out under the supervision of the writer by the Forest Service in the spring and fall of 1924, but owing to the natural prejudice of the forestry men to the use of fire in the forests the method had to be dropped.

In 1925 the method was adopted by the Forest Supervisor on account of the advantage of cleaning up the brush. It was also put into effect by the Park Service in the clean up of Greenland plateau. This method proved to be not only as effective as the peeling method; but disposed of the slash from the control operations and in certain cases was found to be cheaper than the peeling method, especially when the trees could be felled and burned in groups.

In order to gain an idea of the effectiveness of this method, 55 trees of diameters from 10 to 36 inches were examined in July 1925 on the area treated by the Forest Service in the spring of that year. All trees up to 20" d.b.h. showed a 100% kill. Above 20" some of the butt logs had patches of unburned bark on top. It was expected that the beetles under this bark would be killed by the heat of the sun and this did occur in the thin barked trees but some of the thick bark protected the beetles and allowed them to continue their development. However, including all such trees the burning method destroyed 99% of the broods.

From the burning work carried on by the Forest Service and Park Service during 1925, it was found that the cost of treatment varied directly with the cost of labor, the diameter of the trees and with the number of trees in the group. It was also very greatly affected by burning conditions, ease of control of fires and the efficiency of the crew. For trees felled in groups, partially trimmed, a fire line made and burned the following empirical cost formula was deducted:-

$$C = c\,(.9n + .1)\,(.07D^2 + 1.9D + 25)$$

where

C= total cost of burning a group.
c= cost per man minute of treaters time.
n= number of trees in the group.
D= average diameter of trees in group.

Thus the cost of burning one tree of 20" d.b.h. at an average cost per man minute of 1.5¢ would be $1.36

Treatment By Log Rolling.

During 1924, Edmonston and Hofer carried out some experiments under instructions from Dr. Craighead in felling trees, exposing them to the sun and then when the beetles were killed on the top sides of the logs, rolling the logs and exposing the other side. These experiments gave very satisfactory results. Dr. Craighead proposed then that this method be tried out on a larger scale and in a practical way during the control work of 1925. This was done, and on both the Forest Service and Park Service areas enough trees were treated by the rolling method to gain a very good idea of the results and the cost.

On May 22nd the Forest Service camp felled 130 trees on the eastern portion of section 15 T 38N, R 2 E. Pupae were quite plentiful at this date. The trees were felled, as nearly as possible, north and south, and in openings where the sun's rays would reach them. Some trees, however, of necessity were felled on north slopes and in draws where the sun's rays could not reach them.

On June 9th, these logs were examined. New adults were found on the tops of many of the logs, apparently having been speeded up in their development by the warmer conditions. On tops of ridges and on level ground, many logs showed the broods completely killed on the top half of the logs for a log's length or two but if the top or butt happened to be in the shade of other trees no mortality occurred. Many logs in the shade showed no brood mortality. On east and west slopes conditions were similiar. The tops of some logs showed sun killing, others did not. On south slopes, logs showed a little higher mortality than on the east or west slopes although many logs still had full healthy broods on the tops of the logs and underneath as well. Trees on north slopes or in draws showed little or no mortality.

On June 22nd, the logs were again examined. Very little additional killing had occurred since June 9th. It appeared that the broods in logs with thin bark laying so as to receive full sunlight for a good part of the day died with the first hot day, but logs in shaded places or in the shade for a part of the day, or with bark over and inch and a half thick never did reach high enough temperatures to cause any brood mortality.

On level ground very little additional killing had occurred since June 9th. Every log showed live beetles in some portion of the top half.

On a gentle northeast slope, beetles were found to be abundant on the tops of logs having bark over 1 inch thick even though the logs lay in full sunlight for most of the day. The angle of incidence here was not great enough to produce high temperatures. On south slopes, some additional killing had occurred since June 9th, but many trees still showed heavy broods throughout even though only partially shaded by other trees. At this time no logs were found to be ready to roll, therefore, the experiment was abandoned and the trees were peeled before the camp closed on June 28th.

On Greenland, the Park Service tried out other modifications of the log rolling experiment.

On section 26 T 33N, R 4 E, the trees were felled north and south and a strip of bark was removed along each side of the log. The trees were trimmed and left in this condition for a week then the crews returned and peeled any bark which was found to still contain live beetle on the top portion and the logs were turned completely over and left. The same variations in effectiveness of sun killing were found on this area as on the Forest Service area but the trees were rolled nevertheless and the beetles left to their fate. Probably many emerged but a recruise in the fall only brought to light two infested trees. The decline, however, was so great throughout the forest that the amount of new infestation which developed would in any case be no criterion of the effectiveness of the method.

On Section 27, the trees were peeled for 2/3 of their circumference and then rolled and the unpeeled portion left turned towards the sun. This was found to be a quicker method than returning to roll the logs as was done on Section 26. Allowing the men to leave one third of the bark, however, tends towards sloppy work and the leaving of a great deal more than one third. As a consequence on this area the crew had to be sent back to repeel many trees.

Comparison of Costs of Burning and Peeling Methods.

TableIIIshows the relative average time of treating trees by the burning and peeling methods during the spring control of 1925 on the Forest Service area.

These averages indicate that peeling is the cheaper method for treating single trees under 30" d.b.h. Over 30" the two methods require practically the same amount of time with a slight advantage for the burning method.

For trees in groups of two or more the burning method is the cheaper.

Comparative Costs.

Taking the records from both camps, it is possible to gain a very good idea of the relative costs of the various methods. These relative costs are given in Table IV. Thus the peeling method without trimming, piling or lopping of the brush is the cheapest method, while the rolling method combined with partial peeling is the most expensive.

Considering efficiency in connection with cost, the burning method with a cost of $1.63 to 1.53 per tree and a 99% kill of beetles is probably the most efficient.

The thorough peeling work of the Forest Service was 97% effective and the relative cost was $1.66 per tree. This work was, therefore, only slightly more expensive than the burning and not quite as efficient. From a practical standpoint, however, there is very little difference in the cost and efficiency of the two methods. The decision as to the one to be used will therefore have to be based on other considerations such as effectiveness of brush disposal, fire hazard, salvage etc.

The peeling work done at a relative cost of $1.28 per tree was not efficient, and in years of increasing infestation the beetles which escaped in such work might easily offset the benefits of cheaper cost.

EFFICIENCY OF SPOTTING.

Experience has shown that even with the most careful strip spotting some trees will be missed by the spotting crew. To gain an idea of what percent of infested trees can ordinarily be located in control work the following records have been summarized.

Number of Trees Picked Up After The First Spotting of a Section.

Greenland Plateau Control of Spring 1925.

Location	First Spotting		Subsequent Spotting		Percent Spotted In First Spotting.	
	Trees	Volume	Trees	Volume	Trees	Volume
T 33 N, R 4 E						
Sec. 14	67	13,730	6	550	92%	96%
" 15	416	79,180	31	2,840	93%	96%
" 22	506	121,060	6	1,810	99%	99%
Total	989	213,970	43	5,200	96%	97%

Jacob Lake - Control of Spring 1925

Location	First Spotting Trees	Subsequent Spotting Trees	Percent Spotted First Spotting
T 38 N, R 2 E Sec.4	73	10	88%
5	27	0	100%
9	228	21	92%
10	264	37	88%
14	106	77	58%
15	564	17	97%
16	246	51	83%
T 39 N, R 2 E Sec22	64	4	94%
23	158	2	99%
26	170	1	99%
27	107	28	79%
28	49	2	96%
29	33	0	100%
32	30	2	94%
33	54	4	93%
34	172	1	99%
35	99	10	91%
Total	2444	257	91%

Number of Trees Picked Up After Control Work Finished

Control - Spring 1924 (Fall Recruise)

Location	Trees Treated in Control	Recruise Pickups	Percent trees Treated
T 38 N, R 2 E, Sec.32	3,207	224	93.5%

Control - Spring 1925 (Fall Recruise)

Location	Treated in Control Trees	Treated in Control Volume	Recruise Fall pickups. Trees	Recruise Fall pickups. Volume	Percent Treated In Control. Trees	Percent Treated In Control. Volume
T 39 N, R 2 E Sec. 22E½:						
	67 trees	11,210	11	790	86%	94%
T 38N,R2E Sec. 10W½	73	16,080	17	1,020	81%	94%
" " " 15E½	178	43,000	6	670	97%	98%
Total	318	70,290	34	2,480	90%	96%

The above results are given only for sections where data were available, so can only be used to show in a general way what percentage of trees can be located and treated, and cannot be used to show efficiency of the various camps or seasons work.

In general the results show that about 90% of the trees can be spotted in the first spotting of an area and that together with the pickups of the treating crews, fully 96% of the infestation can be located and treated.

Efficiency of Fall Spotting.

The Black Hills beetle attacks the trees during August. By the first of September the attack of trees is practically over. From the first of September on the newly infested trees can be located chiefly by the boring dust around the base of the trees. To determine just what percentage of these infested trees can be located in the fall either in control work or in a fall survey, some of the spotting which was done at Dry Park in the fall of 1924 was rechecked to determine the percentage of trees missed in that work. The results were as follows:

Fall Spotting (September 12-October 9, 1924)

Location	First Spotting Fall 1924 Trees	Second Spotting Fall 1924 Trees	Recruise Fall 1925 Trees	Percent Spotted First Spotting.
T 36 N, R1E Sec 24	246	87	46	65%
T 36 N, R2E Sec 31	92		48	66%

During the fall work of 1924 with a double cruising of the area and with the trees picked up by the treating crews, 88% of the infestation was located and treated on section 24. Section 31 was not treated. For both sections about 65% of the infestation was located in the first spotting. Therefore, in making estimates from fall cruising, the actual number of trees spotted should be considered as 65% of what is probably on the area, and the estimates increased to this extent.

SOME NOTES ON SEASONAL HISTORY OF DENDROCTONUS PONDEROSAE AS RELATED TO PERIOD OF CONTROL.

In 1925 the first control on Greenland Plateau at an elevation of 8,600 feet, and general southern exposure, was started on May 9th. At that time many of the trees were faded, a few were still green. (At Mile and a Half, Mr. Edmonston noted that all trees remained green up to May 10th, while on May 22nd nearly all had faded. This was at an elevation of 8,200 feet but on a general northwestern exposure.) There was very little snow left on the ground and the fires burned readily without a tendency to spread. The weather gradually warmed up until by May 28th some sun killing was noted on the tops of logs felled for such observations but as yet this was not general. The forest duff had become quite dry and burning became somewhat dangerous, so the burning of brush was discontinued. During the week of June 1st, the weather turned off cold and several inches of snow fell. But on June 10th it warmed up again and became very dry and windy. As a consequence six of the control fires escaped and burned some 200 green trees on 90 acres before they were placed under control. Burning was discontinued after this and the logs were either peeled or rolled until the work closed down on the 30th of June.

When the work started on May 9th the Black Hills beetles were still in the half grown to full grown larvae stage. On May 13th the first pupae from beetles overwintering as larvae were found, and on May 28th the first new adults not yet fully colored were noted. By June 1st the greater part of the brood was in the pupal stage and the new adults were a dark brown in color. By June 15th most of the brood had transformed to the new adult stage but so far none had been found to have constructed exit holes completely through the bark. On June 30th when the control work closed down, practically all of the Black Hills beetles were in the new adult stage, but none had been noted as having emerged.

Quite a number of overwintering pupae and new adults were found on May 17th in unpeeled logs left from the control work of the previous spring. These unpeeled logs consisted of green tops and lightly attacked trees felled during the control work. They evidently were attacked by the beetles early in July and had produced a brood part of which had emerged in the fall of 1924 while the others overwintered as pupae and new adults. On June 5th these logs were again examined but although the beetles had started to construct exit holes as yet none had reached the surface and emerged.

The clerid (Enoclerus sphegeus) was noted as flying and quite plentiful on May 9th. By June 20th their larvae were very abundant and were from one half to three quarters grown. The subsequent pupation and emergence of the clerids was not noted.

TABLE I.

INCREMENT COMPUTATIONS

Sample Acre #1

Dia. Inches	Rings: last Inch.	Width on ring	Increase in dia.	Percent Basal area	Volume per tree	Increment Per Trees	No. Trees	Increment for total	Total Volume
6	34.0	.0294	.0588	3.60%	10	.36	2	.72	
7	28.0	.0357	.0714	3.28%	15	.49	1	.49	
9	58.3	.0172	.0344	1.05%	30	.32	3	.96	
10	55.3	.0181	.0362	.95%	40	.38	3	1.14	120
11	44.6	.0224	.0447	1.15%	50	.58	3	1.74	150
12	28.7	.0348	.0696	1.57%	60	.94	3	2.82	180
14	35.2	.0284	.0568	1.03%	100	1.03	5	5.15	500
15	26.6	.0376	.0752	1.24%	120	1.49	3	4.48	360
16	26.5	.0377	.0755	1.15%	150	1.73	11	19.00	1650
[illegible]	34.3	.0292	.0583	.76%	220	1.67	9	15.03	1980
20	36.2	.0276	.0552	.63%	320	2.02	5	10.09	1600
[illegible]	37.6	.0266	.0532	.57%	420	2.40	5	11.98	2100
24	51.2	.0195	.039	.37%	560	2.07	7	14.50	3920
26	30.0	.0333	.0666	.58%	740	4.29	5	21.50	3700
28	27.3	.0366	.0732	.58%	880	5.10	3	15.30	2640
30	32.7	.0306	.0612	.45%	1200	5.40	3	16.20	3600
32	41	.0244	.0488	.34%	1480	5.03	1	5.03	1480
34	84	.0119	.0238	.15%	1700	2.55	1	2.55	1700
Total	711.6						73	148.68	25,680

Total increment .58% of stand.

TABLE II.

INCREMENT COMPUTATIONS

Sample Acre No. 2.

Dia. Inches	Rings last Inch. No.	Width on ring inches.	Increase in dia. inches.	Percent Basal area %	Volume Per Tree Bd.ft.	Increment Per tree. Bd.ft.	No. Trees	Increment for total Trees bd. ft.	Total volume.
6	59	.017	.034	2.08%	10	.20	18	3.6	
7	63	.016	.032	1.47%	15	.22	10	2.2	
8	57	.0175	.035	1.29%	20	.26	6	1.6	
9	50	.020	.040	1.22%	30	.37	18	6.7	
10	43	.023	.046	1.20%	40	.48	16	7.7	640
11	42	.024	.048	1.24%	50	.62	9	5.6	450
12	37	.027	.054	1.22%	60	.73	12	8.8	720
13	34	.029	.058	1.06%	80	.85	10	8.5	800
14	31	.032	.064	1.16%	100	1.16	11	12.8	1100
15	32	.031	.062	1.03%	120	1.24	10	12.4	1200
16	33	.030	.061	.93%	150	1.40	6	8.4	900
17	24	.042	.084	1.18%	180	2.12	2	4.2	360
18	25	.040	.080	1.04%	220	2.29	7	16.0	1540
20	29	.034	.068	.78%	320	2.50	2	5.0	640
22	26	.038	.076	.81%	420	3.40	1	3.4	420
23	16	.062	.124	1.25%	500	6.25	1	6.3	500
25	24	.042	.084	.76%	660	5.02	1	5.0	660
26	18	.056	.112	.97%	740	7.17	1	7.2	740
36	57	.018	.036	.22%	2100	4.62	1	4.6	2100
Total	700						142	130.0	12,770 bd.ft.

Green Trees & Killed trees . . . . . 1.02% increment per acre per year.

TABLE III.

AVERAGE MAN MINUTES FOR TREATING PER TREE

Kaibab Spring Control 1925

	Av. Dia.	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
Single Trees	Peeled		37	56	74	95	120	155	210		
	Burned		50	61	80	102	128	157	200		
Group of Two.	Peeled		72	83	96	113	132	155			
	Burned		45	60	75	94	121	157			
All groups.	Peeled		59	74	91	110	135	161	220		
	Burned		40	54	74	94	115	138	175		

TABLE IV.

1925 Control Operations Kaibab N.F.
and Grand Canyon National Park.

Comparative Time of Various Operations.

	Trees Treated Per Man Day: Jacob Lake Camp.	Trees Treated Per Man Day: Greenland Camp.	*Relative cost per Tree.
Burning Method:			
Many large groups	4.89		$1.53
Mostly small groups		4.61	1.63
Peeling Method:			
Tops lopped, many logs turned very thorough peeling	4.52		1.66
Tops not trimmed, no logs turned		5.85	1.28
Rolling Method			
Trees cut for rolling, later peeled	3.53		2.13
Trees peeled on sides, later rolled and partly peeled		4.52	1.66
Trees peeled 2/3 and rolled		5.28	1.42
Average for treaters only	4.6	5.0	
Average for all men in camp	2.6	3.1	

	Actual Costs	Cost Per Tree
Burning		
Many large groups		$1.82
Many small groups		$1.58
Peeling		
Tops lopped, many logs turned		$1.97
Tops not lopped, no logs turned		$1.25
Rolling		
Trees cut for rolling, later peeled,		$2.53
Trees peeled on side & later rolled		$1.61
Trees peeled 2/3 and rolled		$1.38
Total Average Cost per tree	$1.93	$1.45

*Assuming an average per man day (treaters only) cost of $7.50

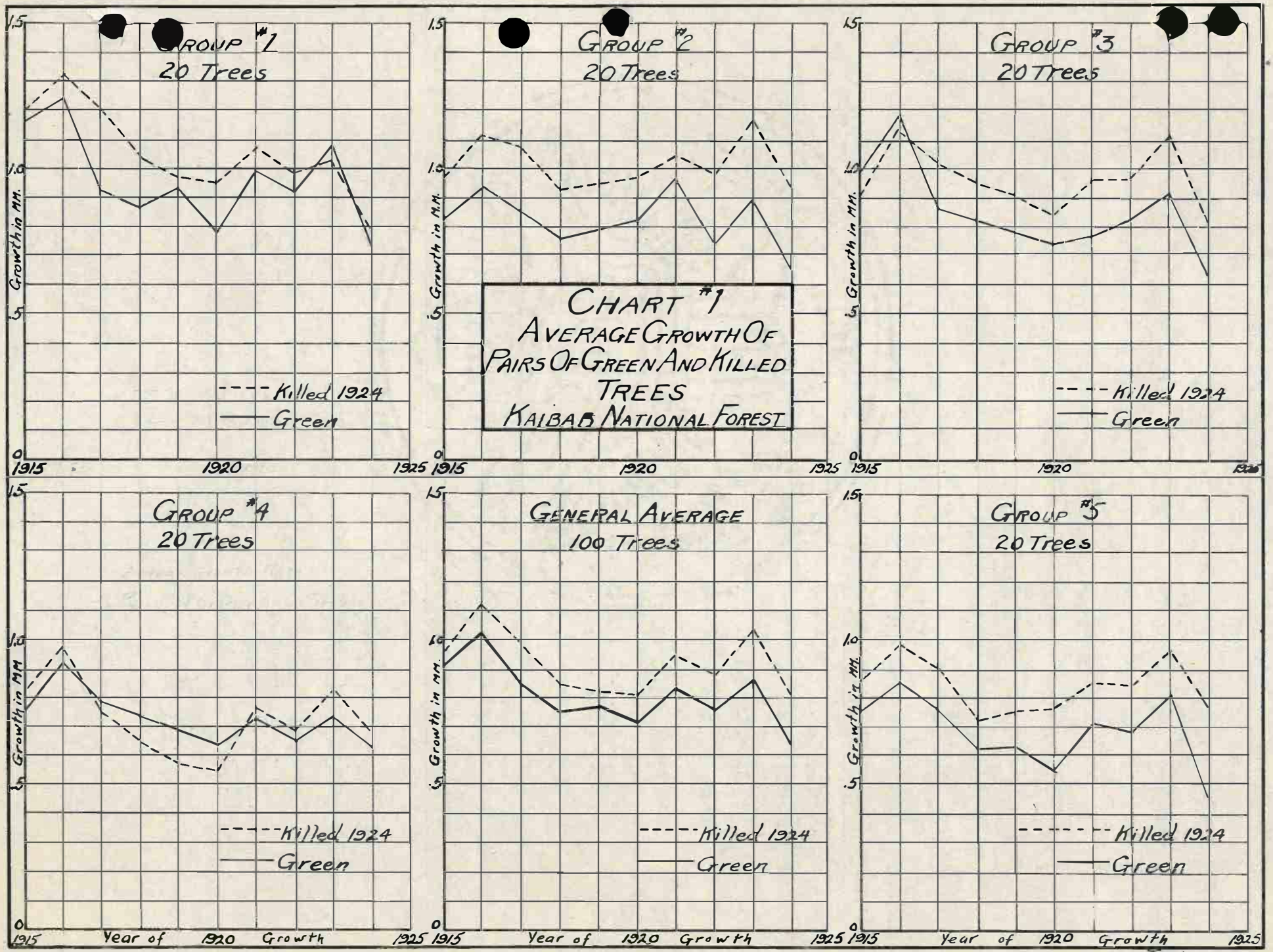
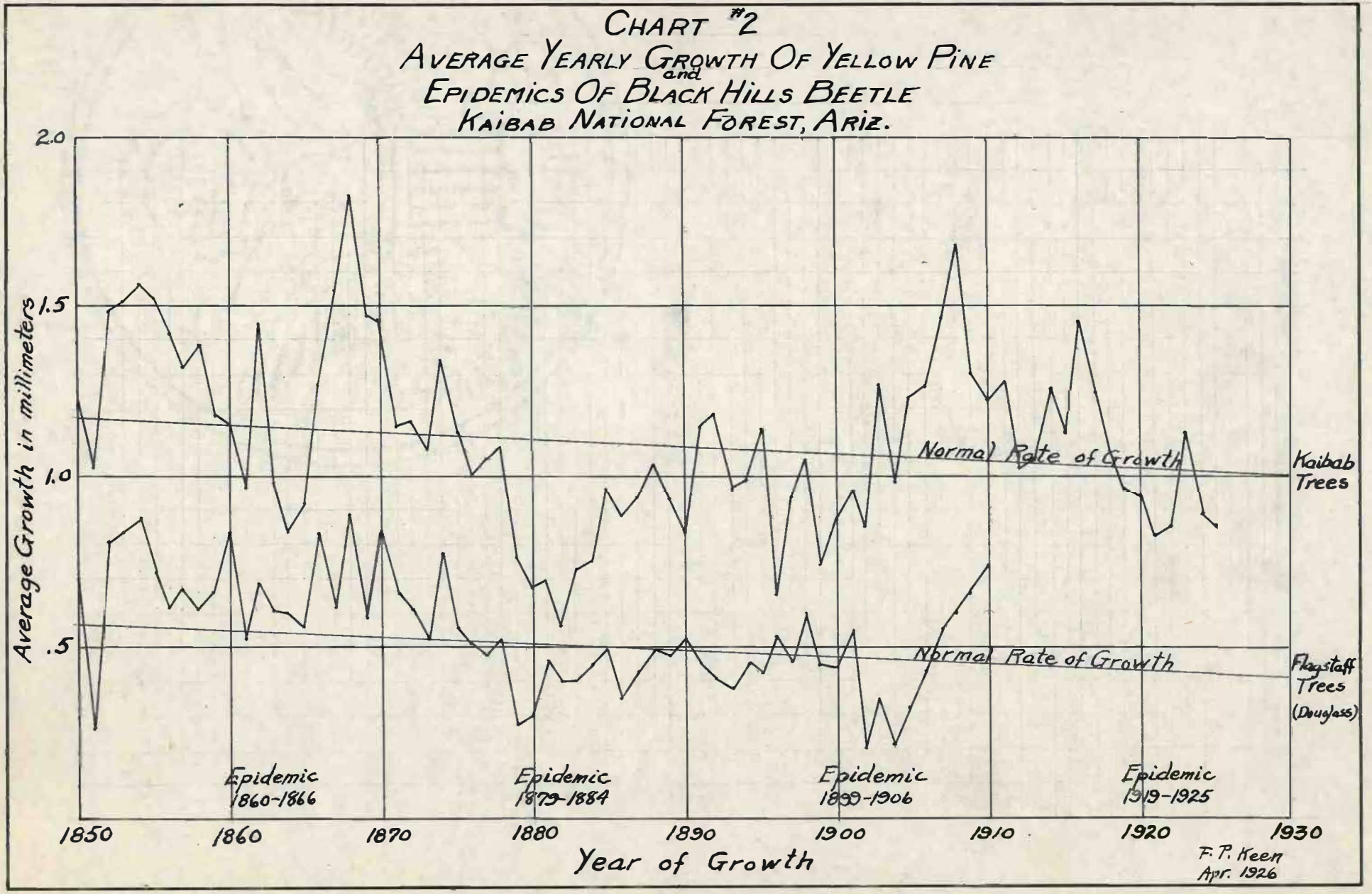

GROUP #1
20 Trees
GROUP #2
20 Trees
GROUP #3
20 Trees
CHART #1
AVERAGE GROWTH OF
PAIRS OF GREEN AND KILLED
TREES
KAIBAB NATIONAL FOREST
GROUP #4
20 Trees
GENERAL AVERAGE
100 Trees
GROUP #5
20 Trees
Growth in MM.
Killed 1924
Green
1915
1920
1925
Year of Growth
F. P. Keen
Apr 1926

CHART #2

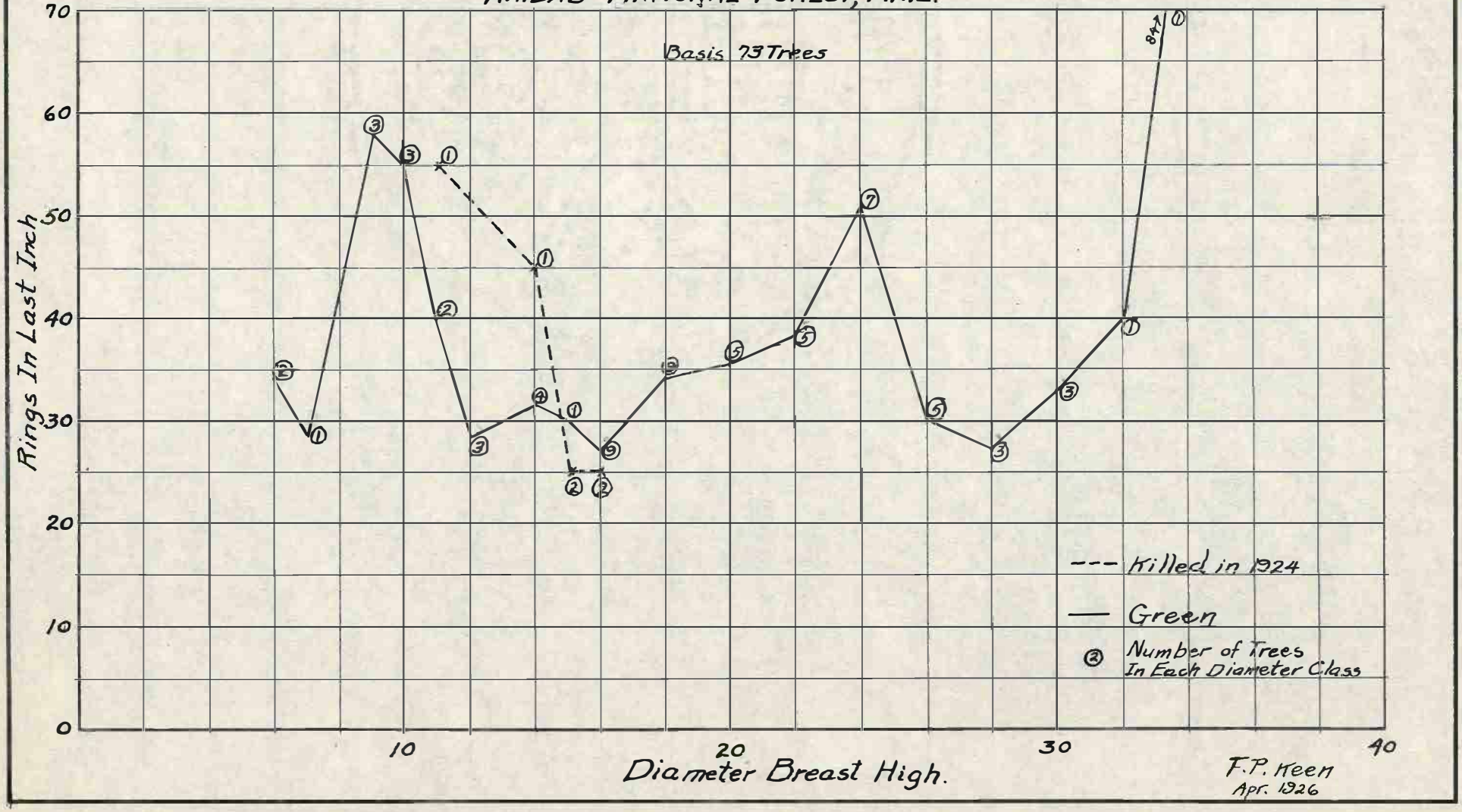
AVERAGE YEARLY GROWTH OF YELLOW PINE and EPIDEMICS OF BLACK HILLS BEETLE KAIBAB NATIONAL FOREST, ARIZ.



F. P. Keen
Apr. 1926

CHART #3

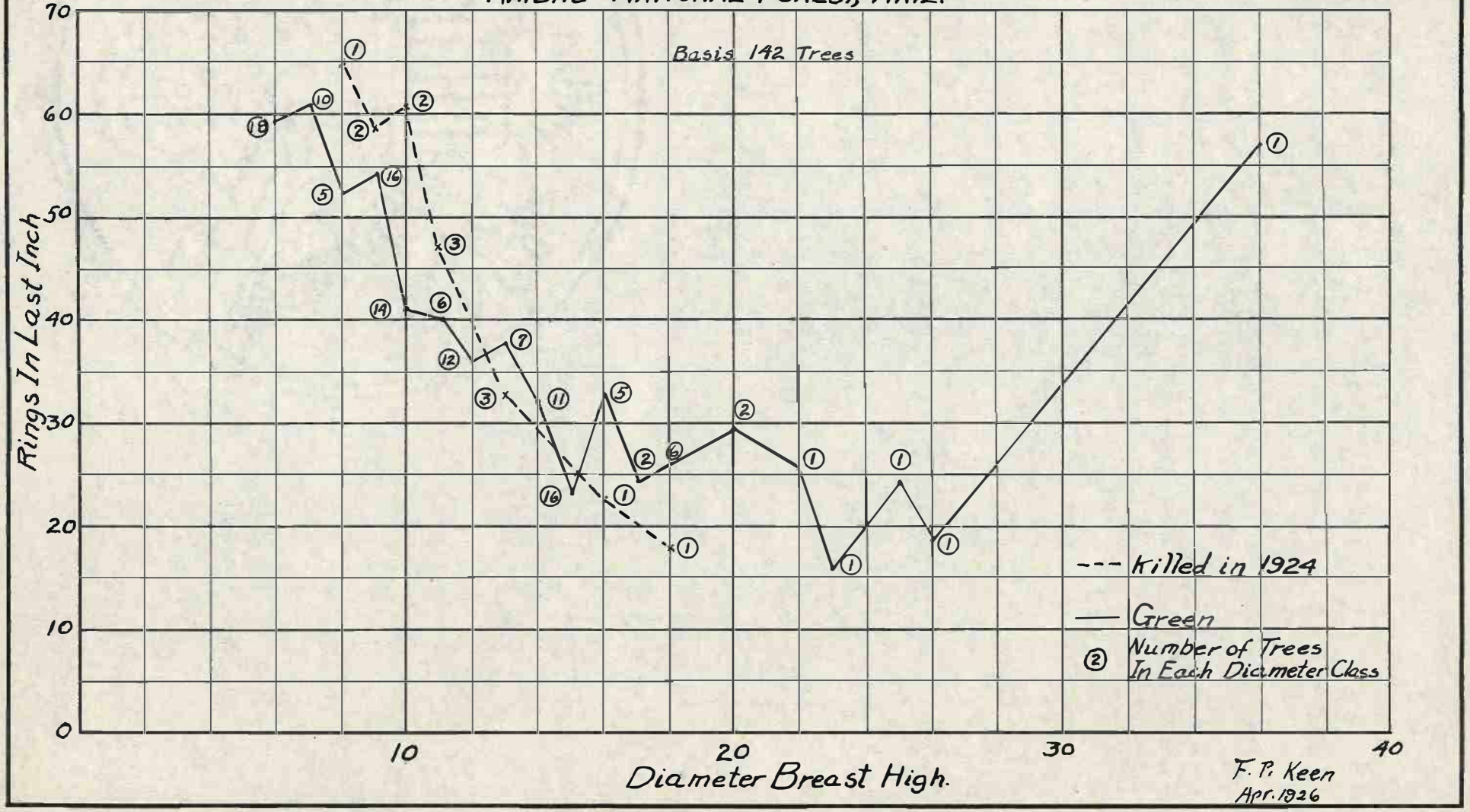
AVERAGE GROWTH OF GREEN AND KILLED TREES ON SAMPLE ACRE #1 KAIBAB NATIONAL FOREST, ARIZ.



F. P. Keen
Apr. 1926

CHART #4

AVERAGE GROWTH OF GREEN AND KILLED TREES ON SAMPLE ACRE #2 KAIBAB NATIONAL FOREST, ARIZ.



F. P. Keen
Apr. 1926